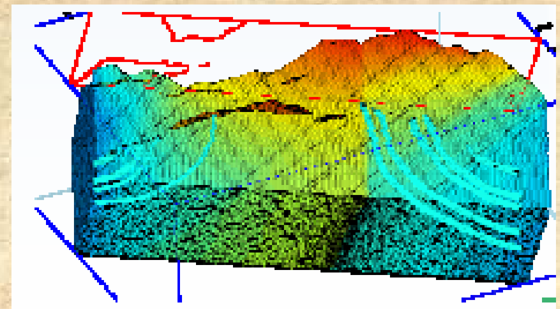
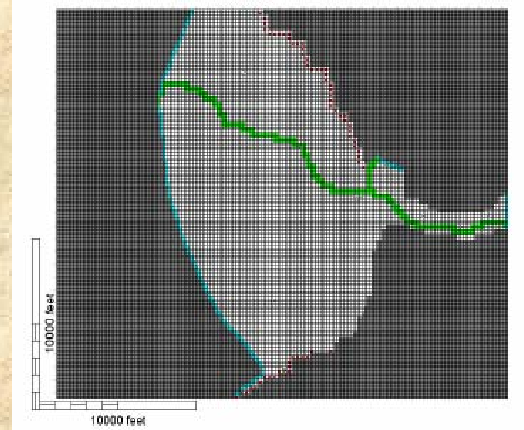
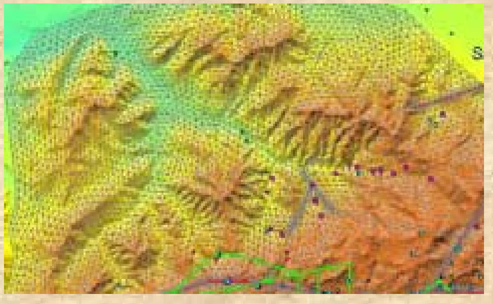
Usefulness of Numerical Models to Address Impacts of Mitigation and Augmentation Actions on Groundwater and Surface Water Systems

Water Policy Interim Committee







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Take Home Points

1. Numerical models can be developed to represent complex geological and hydrological systems.

2. Groundwater modeling is most useful when used to answer…How does the groundwater system work?

3. Analyses of impacts to water resources using ...What if scenarios… provide valuable information on the likely changes that will occur to hydrologic systems.

4. Quantitatively, forecasting short and long term impacts of specific proposed actions includes error and uncertainty.

This Presentation


Floyd Tries to Go On Line

1. What is a model?

2. What types of models are there?

3. How is a numerical groundwater model developed?

4. What are the data needs?

5. Case study to illustrate model application

6. Challenges in using the results.

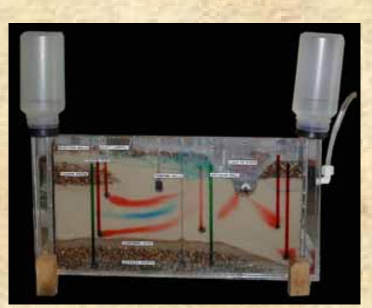
What is a Model?

Simplification of a real world setting.

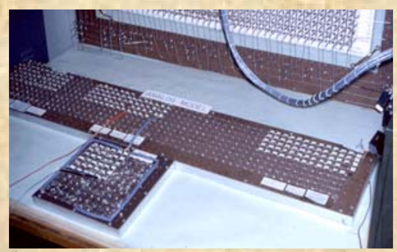
Example- Road map is a model of the earth's surface

Types of Models

1. Physical Scale Model



2. Analog model



3. Mathematical Model

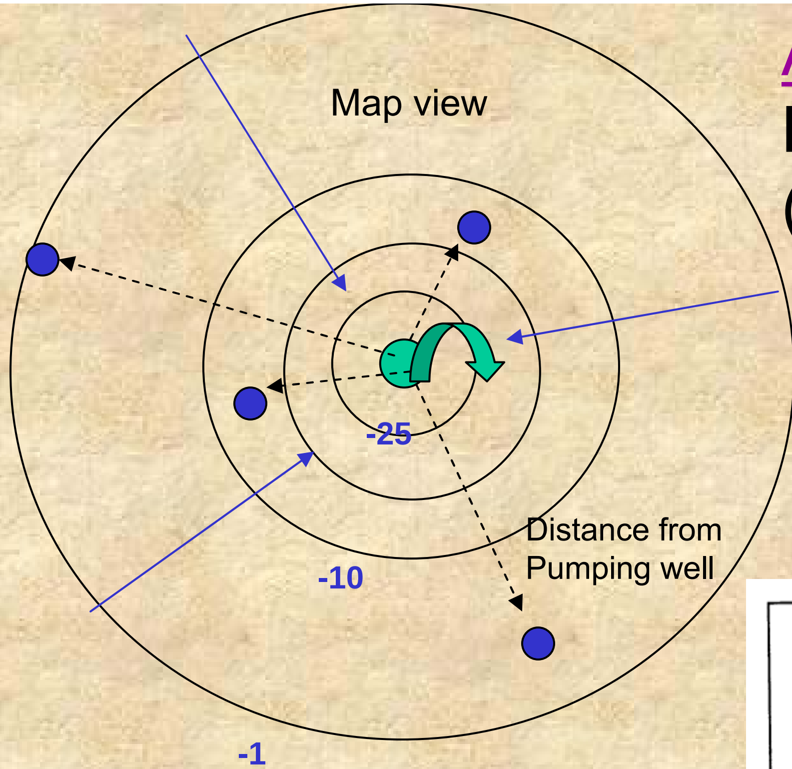
Use physics and math to describe the resource

Analytical Model

$$s = \frac{Q\,W(u)}{4\pi T}$$

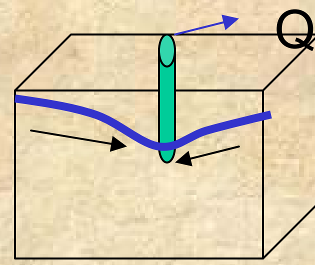
Numerical Model

Finite Differences
Finite Elements



Analytical Model (equation)

Pumping Well- Predict drawdown(s) (reduction in GW levels)

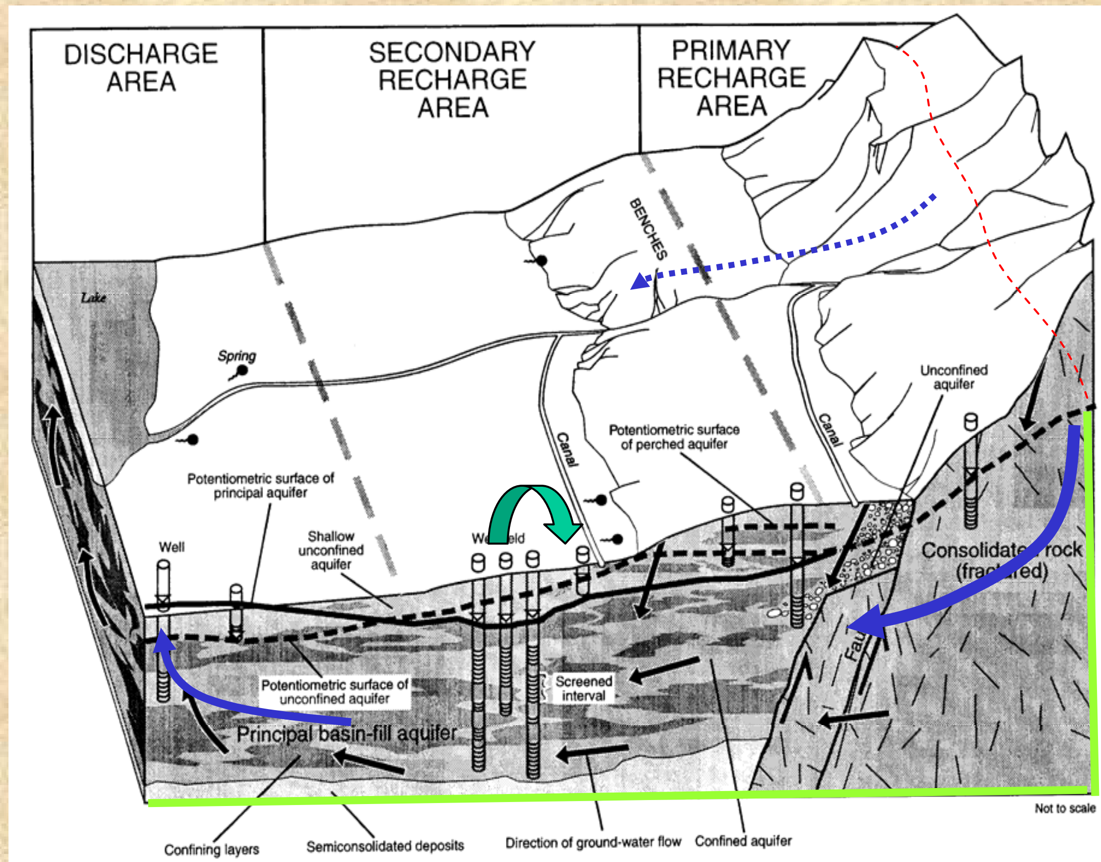


Many simplifying assumptions

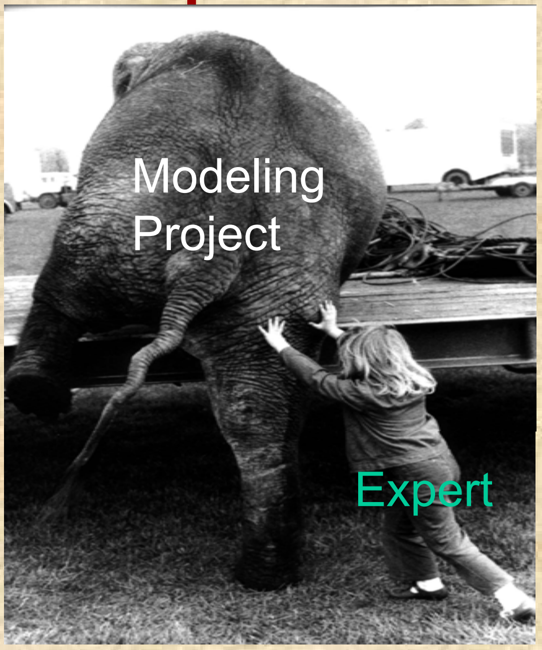
Numerical Model

Handles More Complex GW Settings

Fewer simplifying assumptions



Different amounts and distributions of data are required to solve specific problems.



Increasing Data Needs

Increasing demand for Evidence of Simulation Match with Field Conditions

Generic Modeling

Under general conditions
-how do components interact

Interpretative Modeling

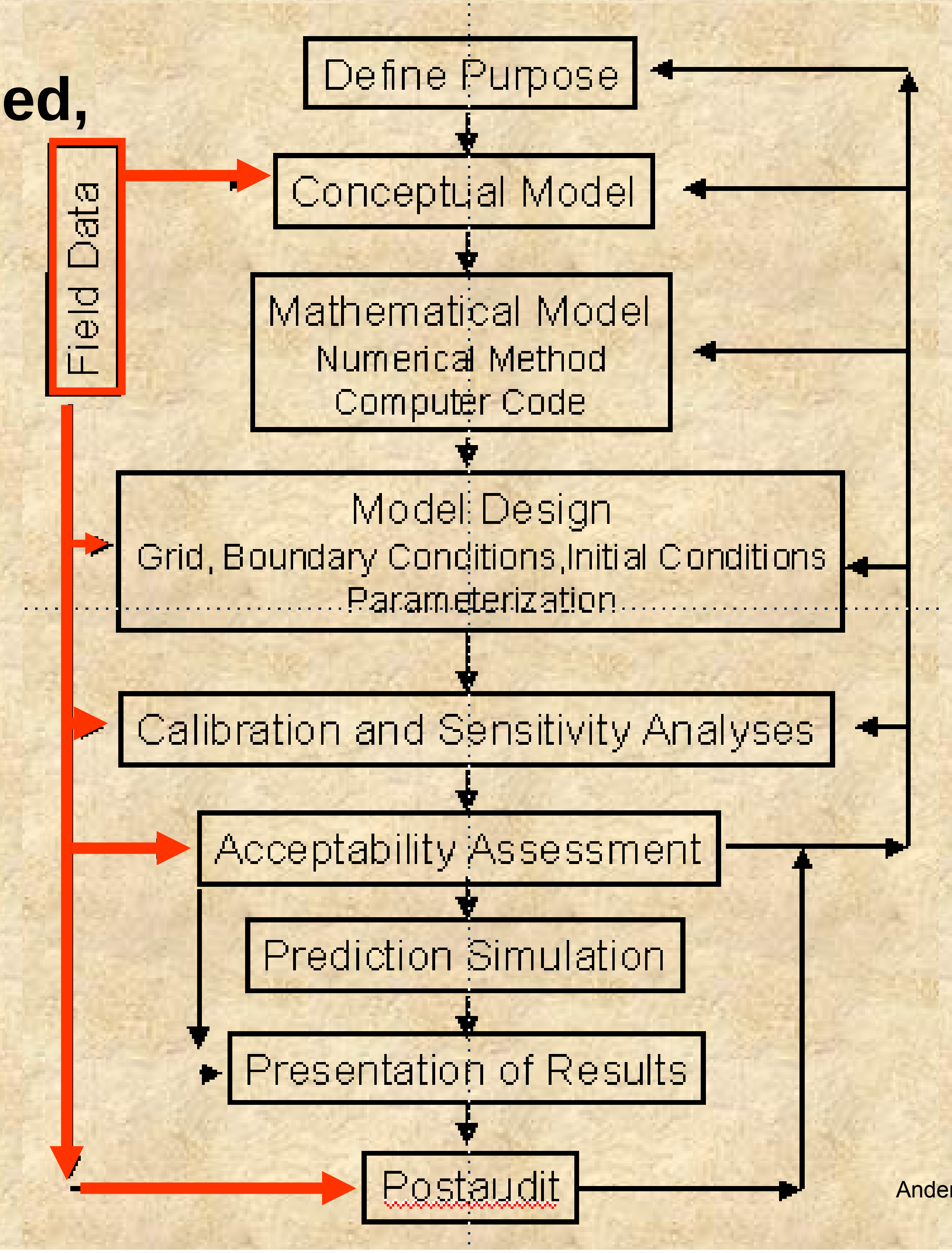
Under field conditions
-how do components interact

Predictive Modeling

Under field conditions
-what are likely outcomes

How are Numerical Models Developed?

An Established, Recognized Method



Anderson and Woessner, 2004

What are the Data Needs?

Building the Conceptual Model

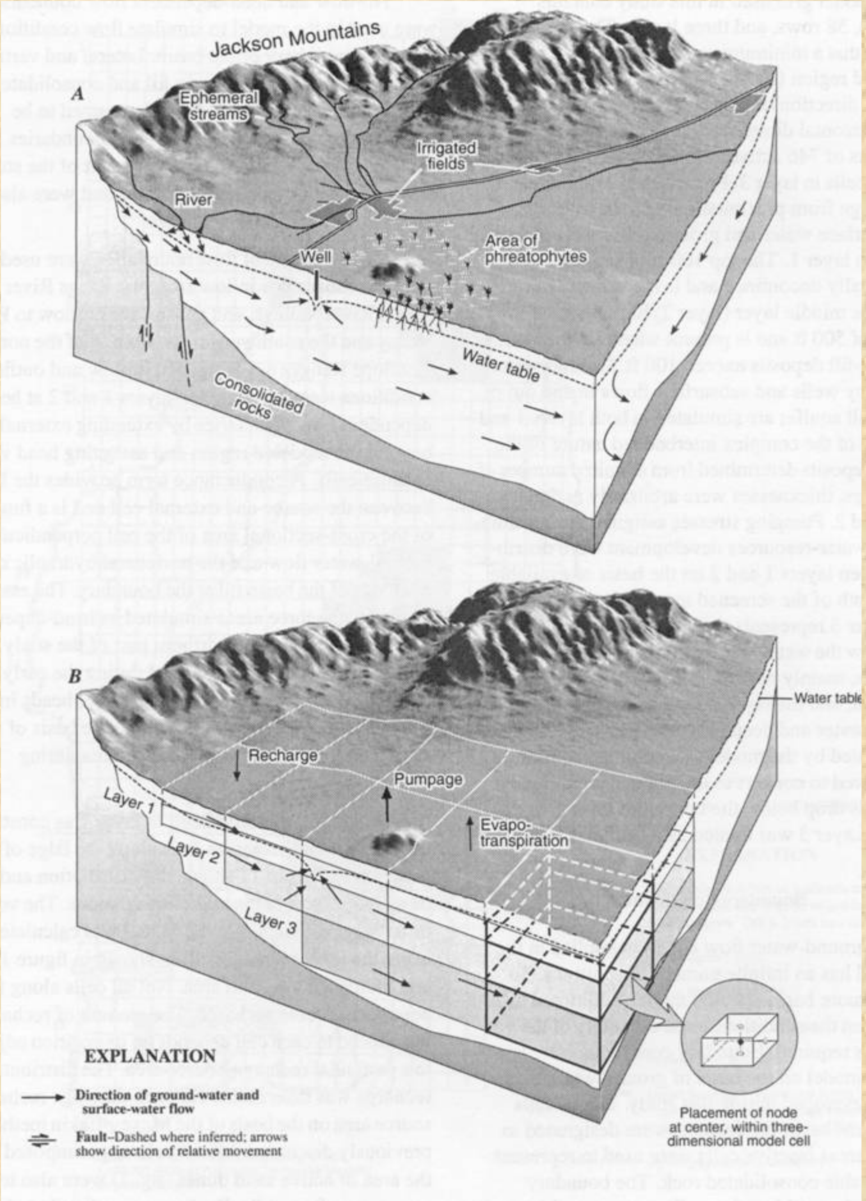
Physical Framework

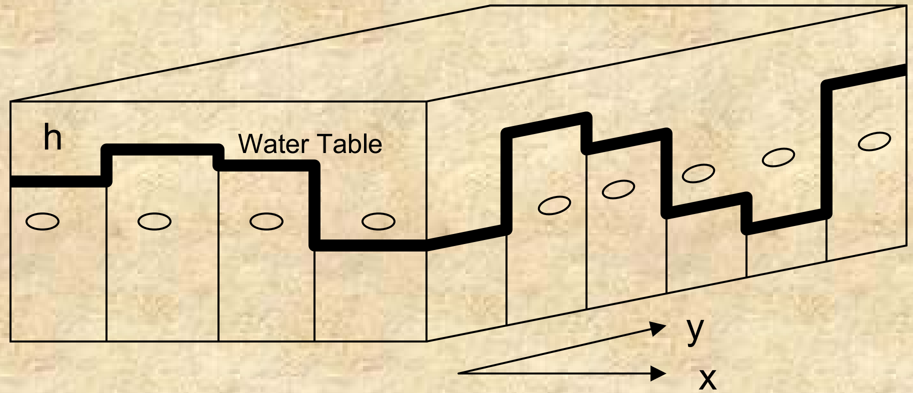
Geology- nature, 3D extent
Surface topography and Soils
Hydrologic Features

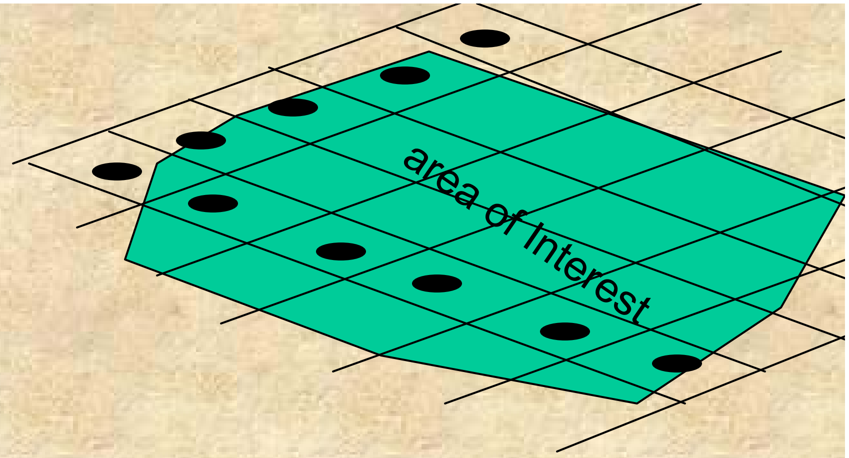
Hydrologic Framework

Water Level Measurements
Surface Water Elevations
Surface Water Flows
Transmission and Storage
Properties of Earth Materials
Sources of Recharge and Discharge
Physical and Hydraulic Boundaries
Source and Sinks of Water
Water Quality Data

It's the Hydrogeology!!

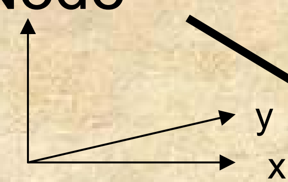


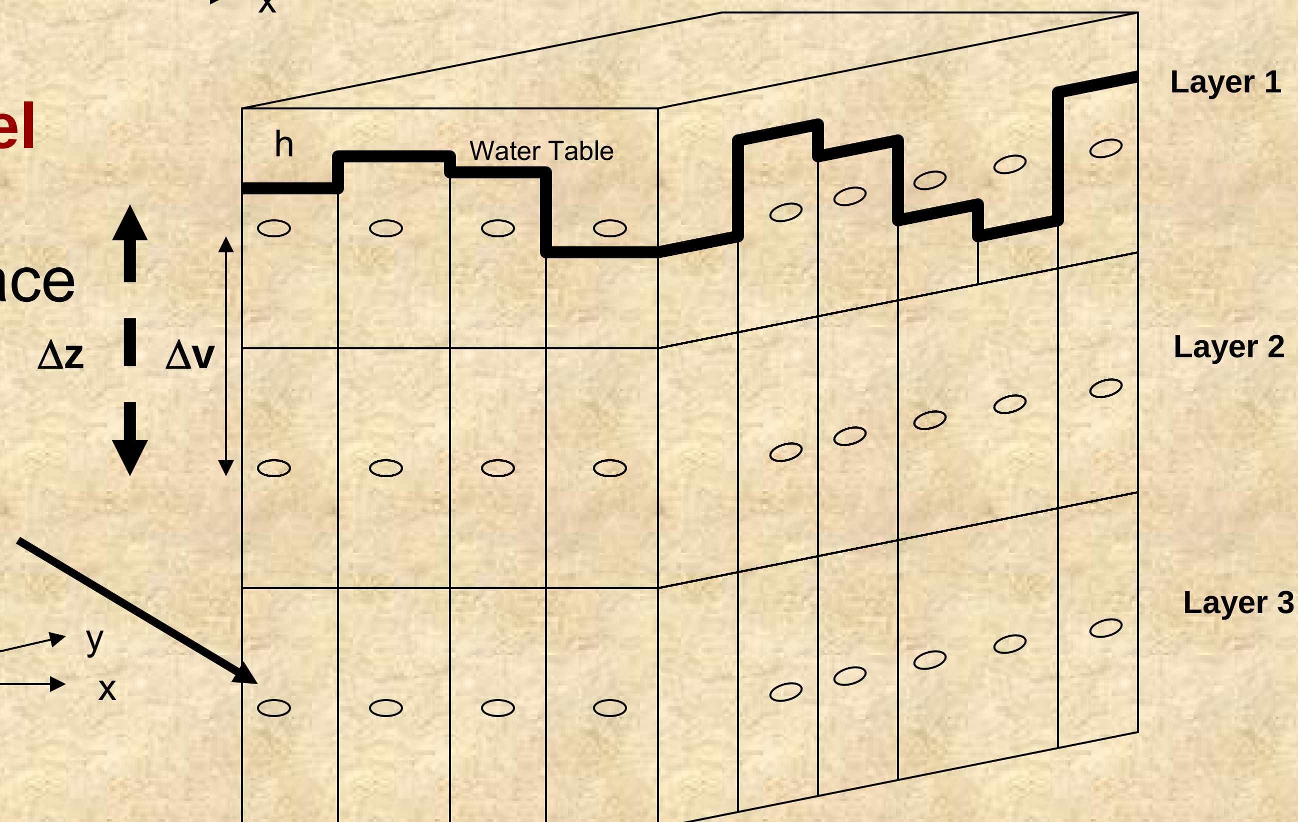




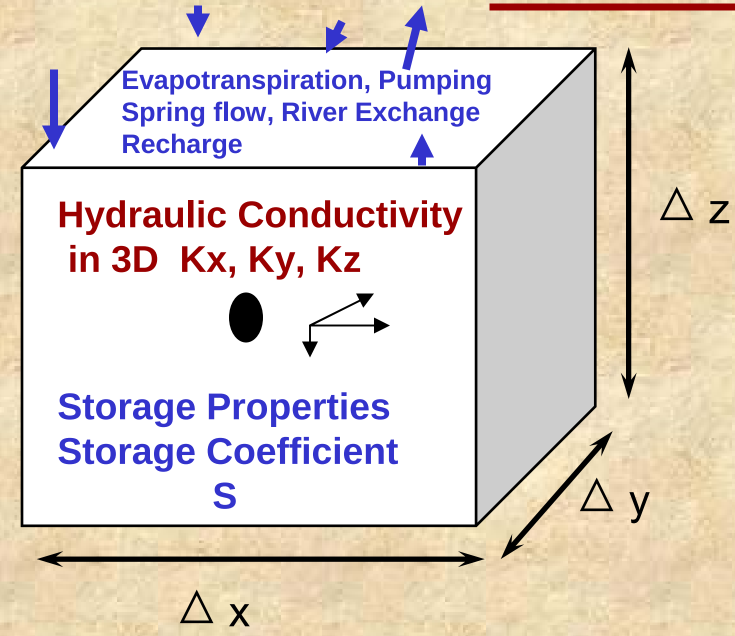
Numerical Model

Break up the space and time into blocks and time Intervals. Node



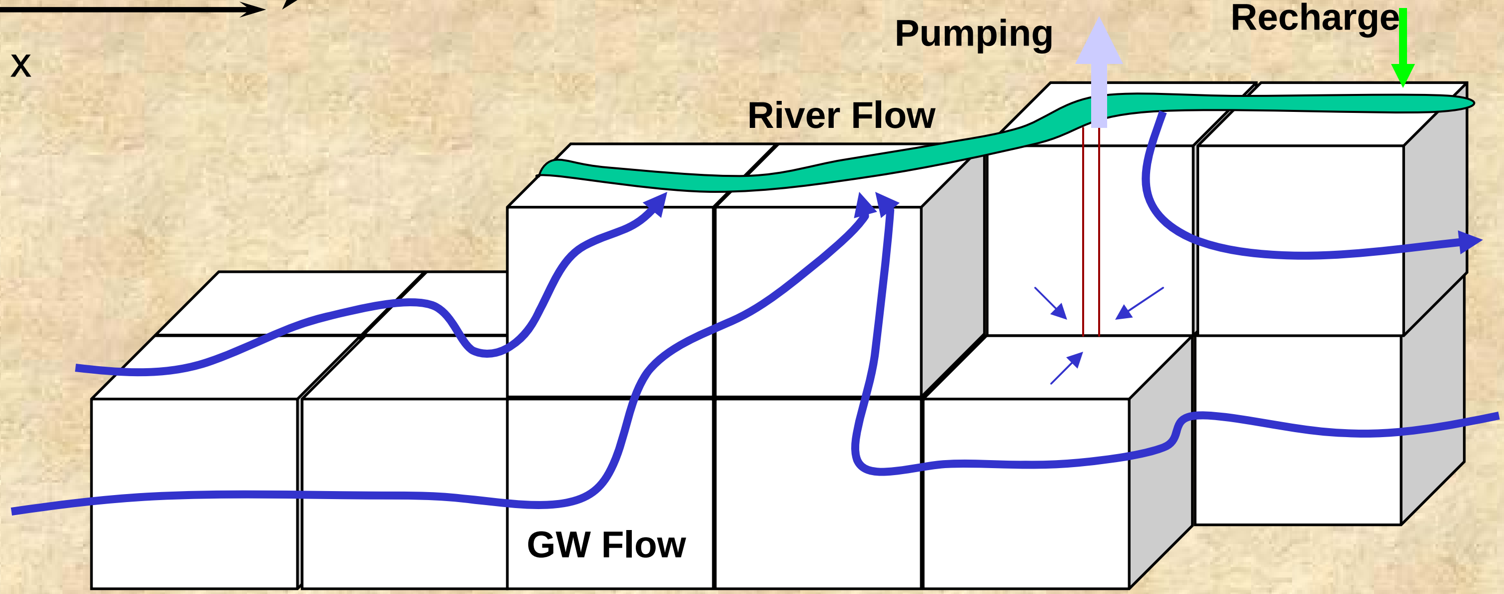


Parameterizing the Model



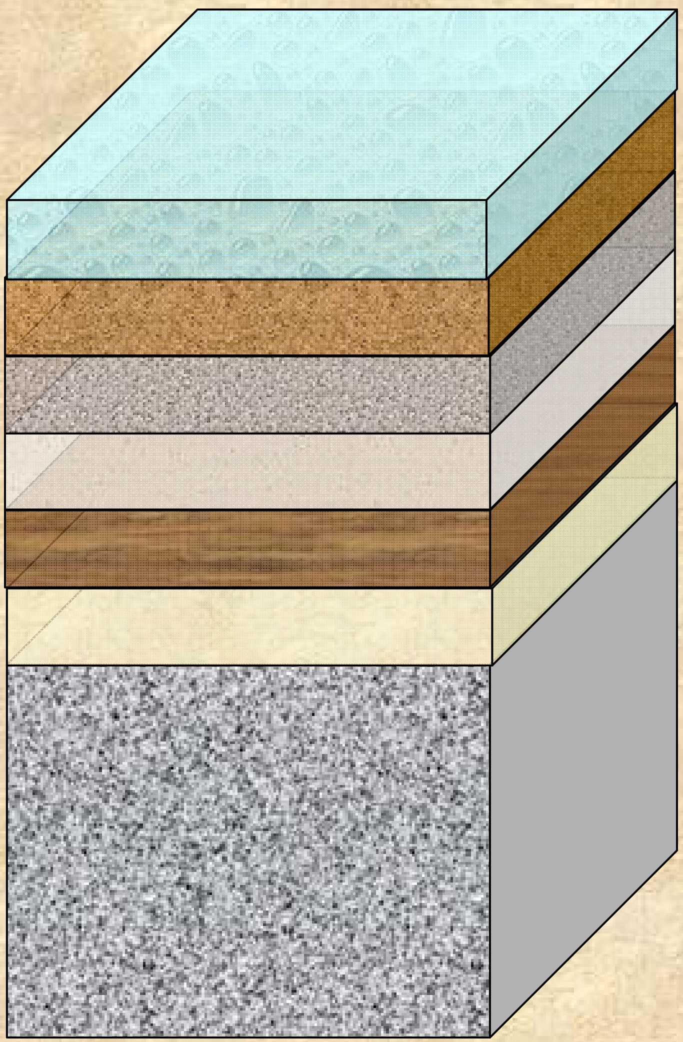
Numerical Modeling Methods Assign Data to Cells or Elements that represent a Volume of Aquifer material

Individual elements are then linked to adjacent cells and the GW model is created.

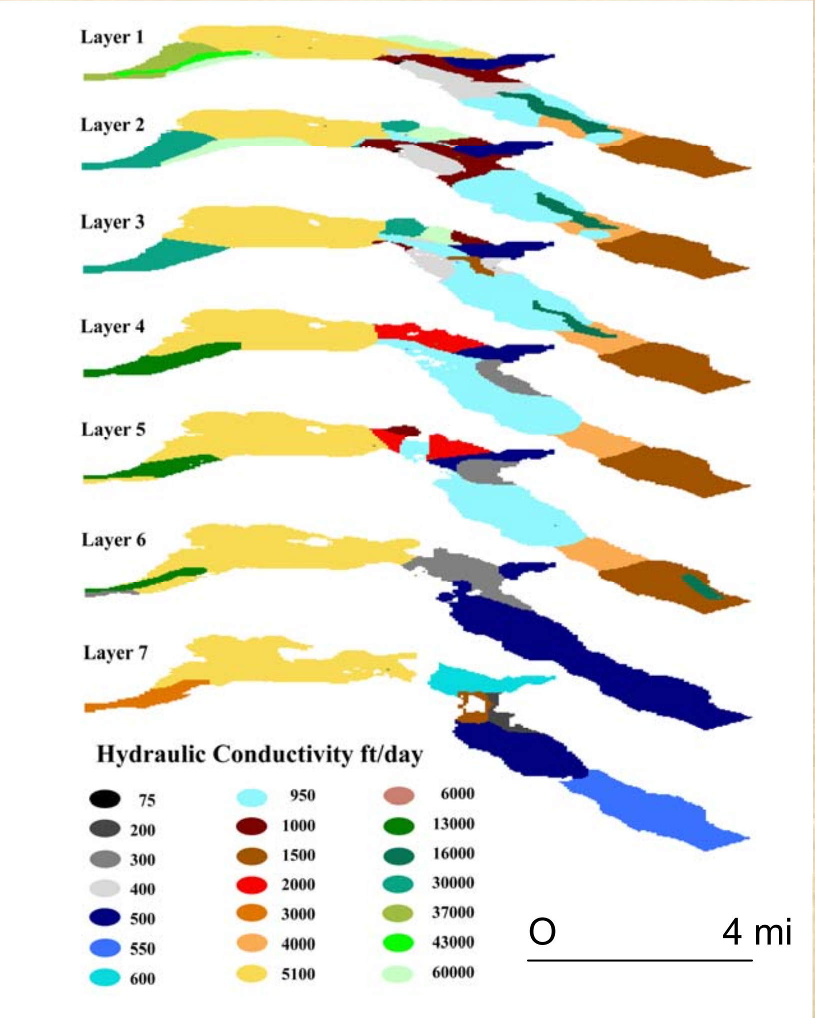


Milltown GW Model example

Seven Layers



Distribution of Hydraulic Conductivity



Milltown (Berthelote et al., 2007)

Case Study Example

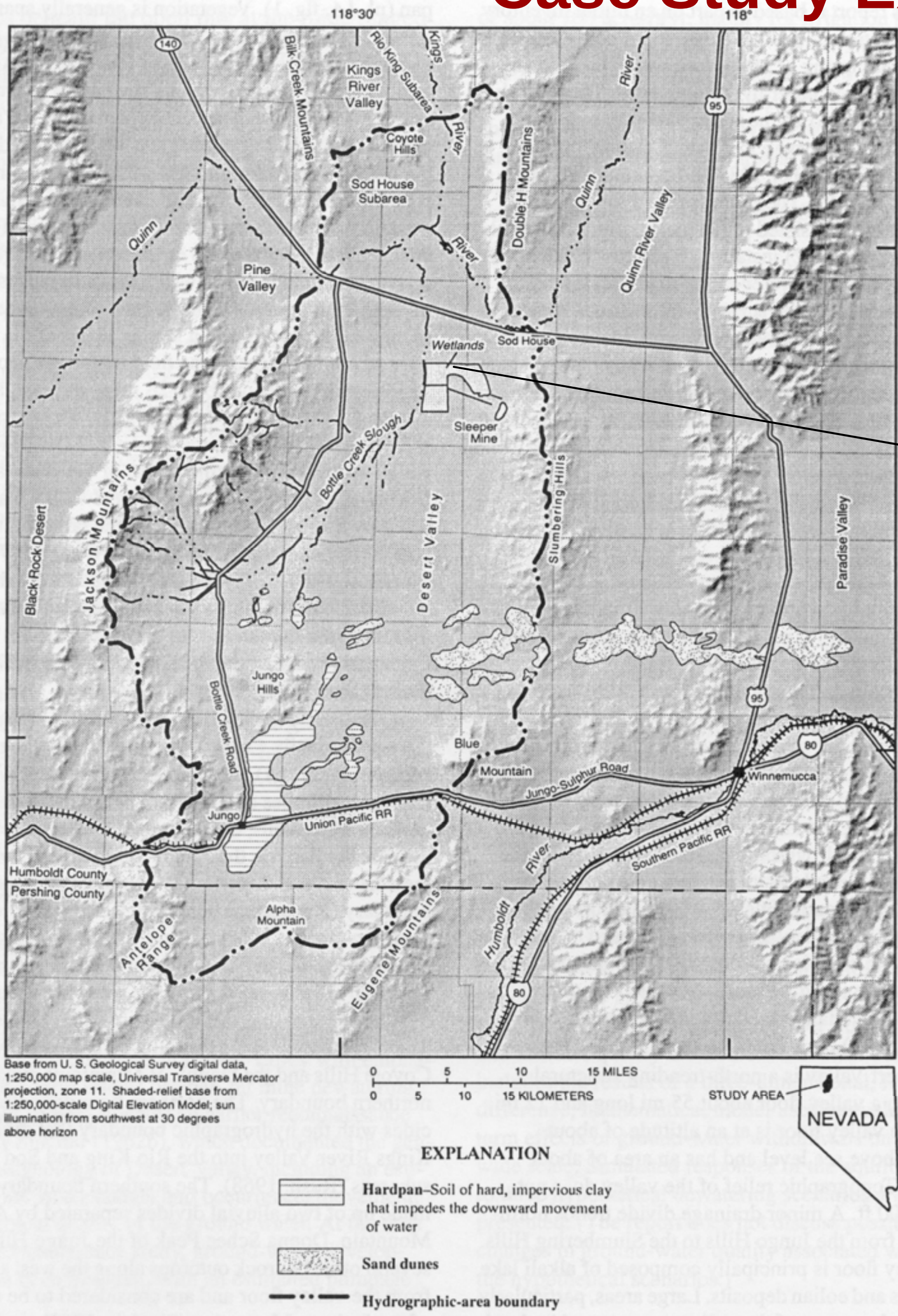
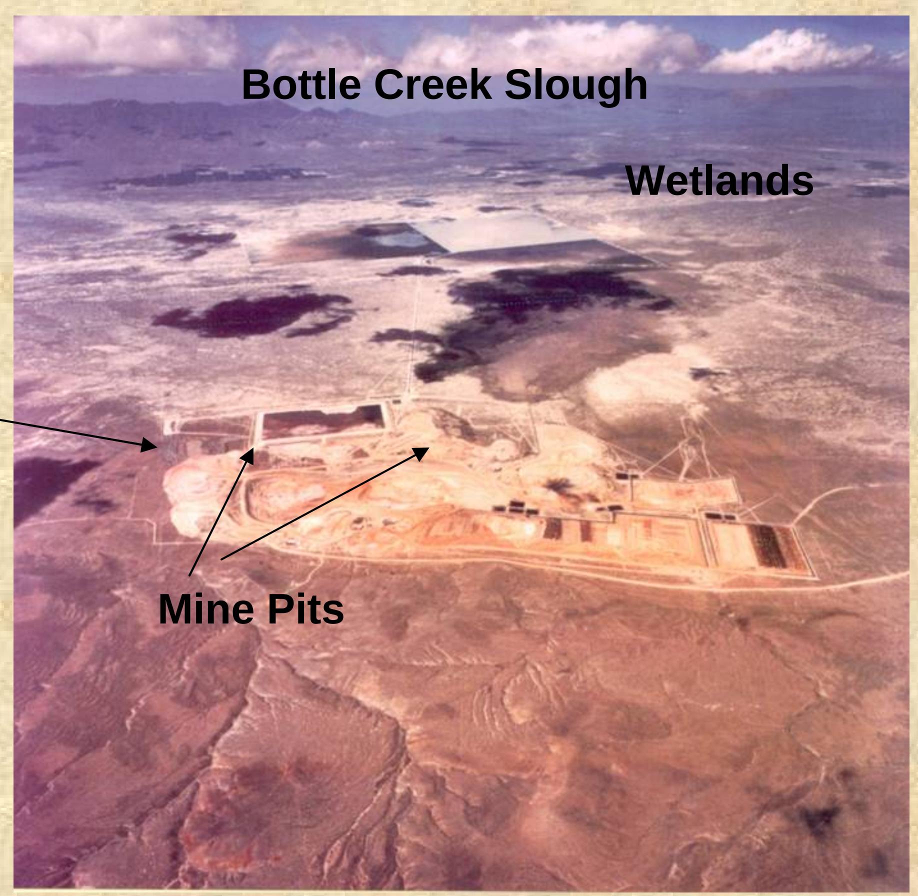


Figure 1. Location and general features of Desert Valley area.



Purpose: Examine the effects of mine dewatering on the ground-water conditions in Desert Valley, NV

Purpose is not to build a model!!!

Formulate the GW Model

Cells in the three layered model

4,524

Assign values to cells

Assign boundary conditions

USGS MODFLOW

Numerical Model

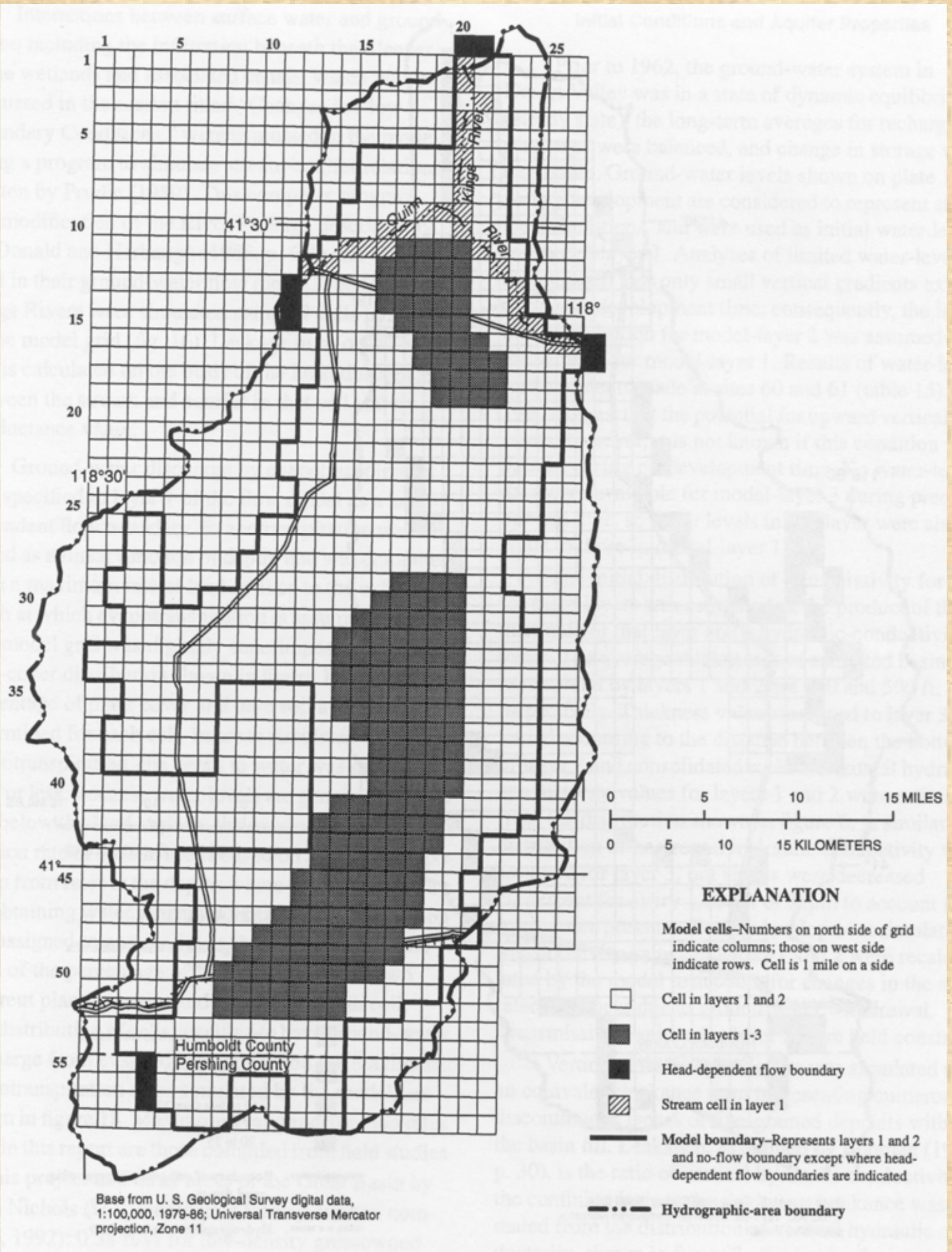


Figure 16. Block-centered finite-difference grid used for ground-water flow model of Desert Valley, Nevada.

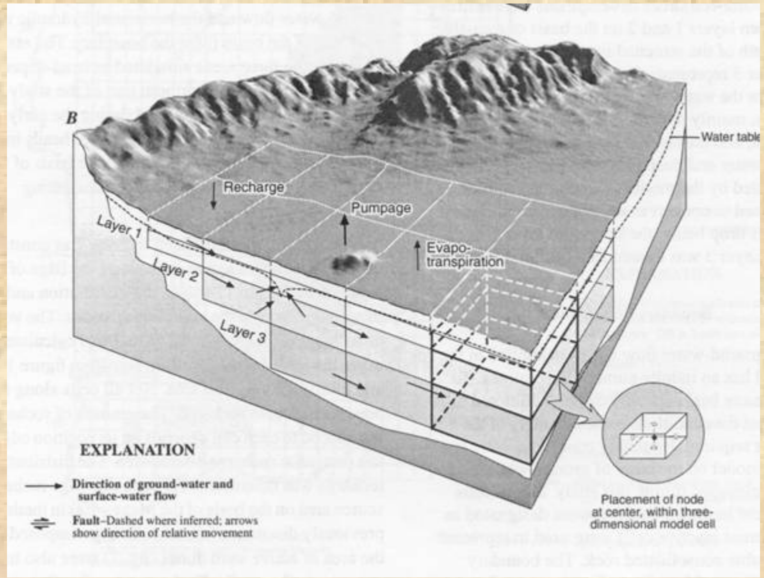


Table 9. Estimated ground-water budget for predevelopment conditions (pre-1962), Desert Valley, Nevada

[All values in acre-feet per year]

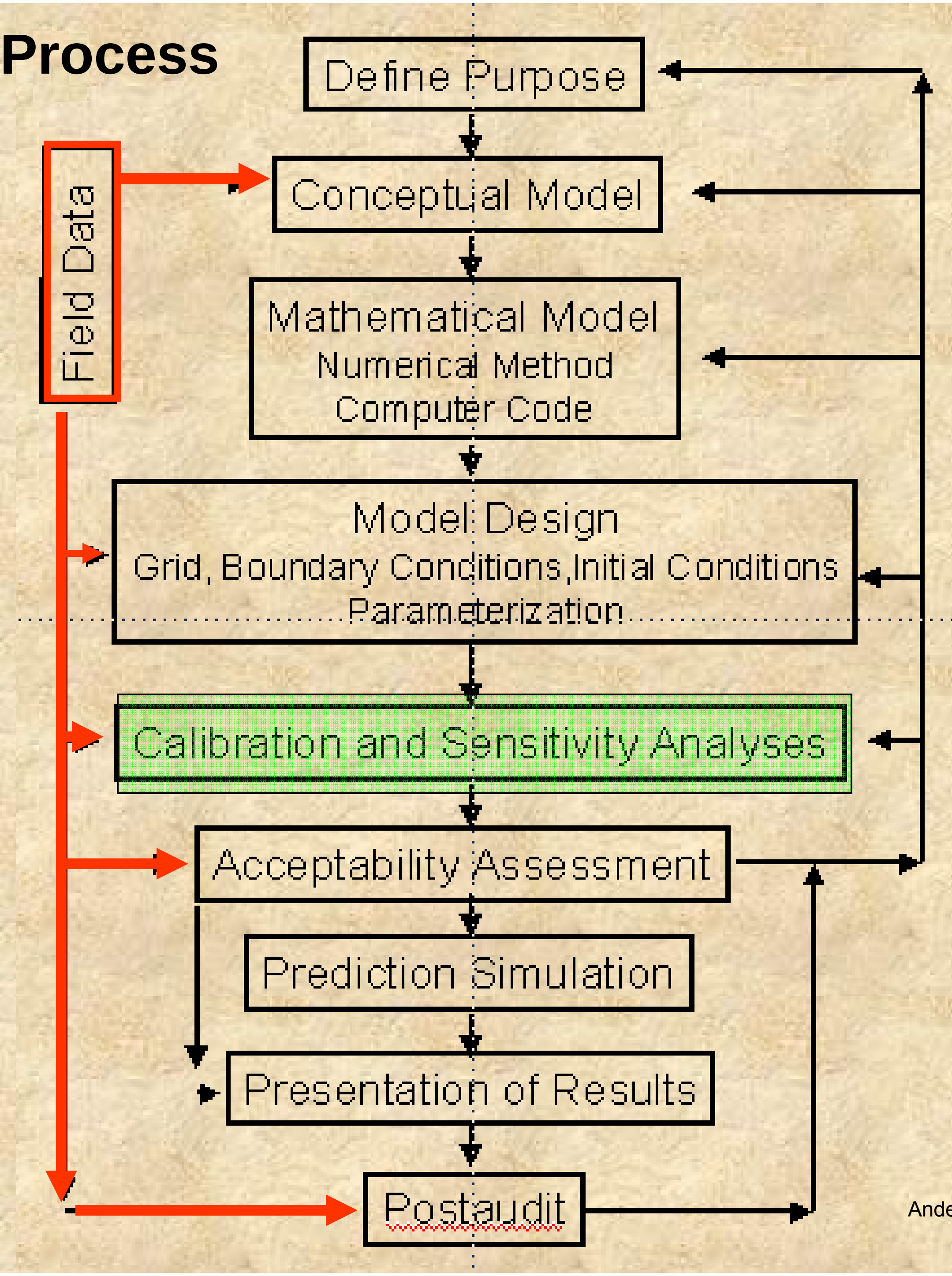
Budget component	Estimated predevelopment conditions
Inflow	
Recharge from precipitation:	
From mountain block (p. 33, p. 34)	3,300 - 6,800
From sand dunes (p. 35)	500 - 1,000
Infiltration from rivers (p. 19)	700 - 4,700
Subsurface inflow:	
From Kings River Valley (p. 16)	900
From Quinn River Valley (p. 16)	300
Total inflow (rounded)	5,700 - 14,000
Outflow	
Evapotranspiration (p. 35)	10,000
Subsurface outflow:	
To Pine Valley (p. 19)	100 - 400
To Southwest (p. 19)	120 - 1,200
Total outflow (rounded)	10,000 - 12,000

Pre-simulation Water Balance

Critical!!!

$$\boxed{\text{In} = \text{Out} \pm \Delta\text{Storage}}$$

Modeling Process



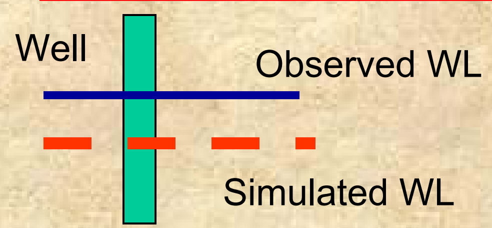
Anderson and Woessner, 2004

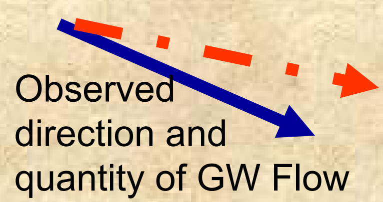
Calibration Process

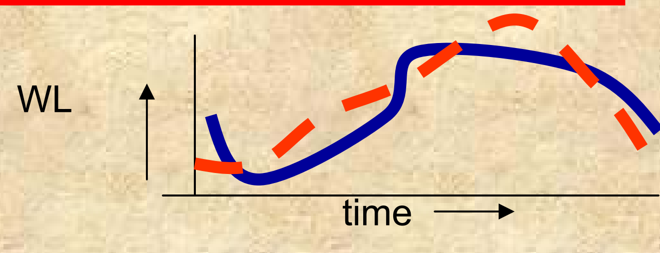
Set Calibration Targets

1. **Differences between simulated and measured heads.**
2. **Differences between measured GW fluxes and simulated fluxes**
3. **Differences in the pre-simulation computed water balance and simulated water balance.**
4. **Differences in locations and rates of pre-simulation and simulation recharge and discharge**.

Using Trial and Error or Automated Parameter Estimation, the model is executed a number of times while adjusting model components such that differences between measured and simulated conditions are minimized







Pre-development 1962 Calibration

Pattern of water levels

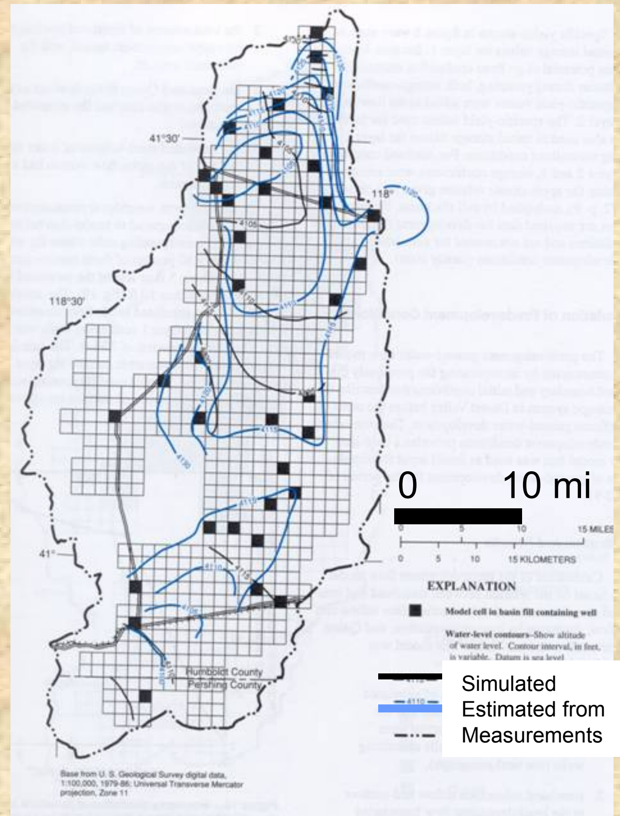


Figure 20. Simulated potentiometric surface for layer 1 and water levels estimated on basis of field data, predevelopment conditions, Desert Valley, Nevada.

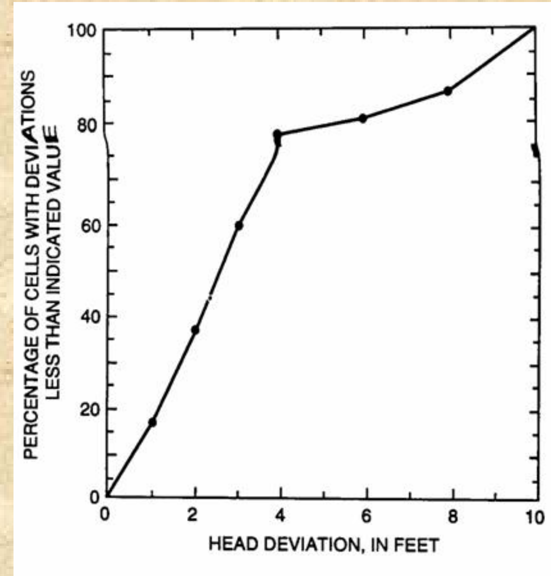


Figure 19. Frequency distribution of deviations between measured and simulated hydraulic heads for predevelopment simulation, Desert Valley, Nevada.

Overall measured and simulated head match

Original Water Balance
5,700 -14,000 Inflow
10,000 - 12,000 Outflow

Simulated Flow at Boundaries
Flow of Quinn River "agreed with estimates".

Simulated Water Balance

Table 11. Simulated ground-water budget for predevelopment conditions (pre-1962), Desert Valley, Nevada

[All values in acre-feet per year, rounded to two significant figures]

Budget component	Simulated predevelopment conditions
Inflow	
Recharge from precipitation:	
From mountain block	6,900
From sand dunes	440
Infiltration from rivers:	
Quinn River	2,600
Kings River	110
Subsurface inflow:	
From Kings River Valley	820
From Quinn River Valley	310
Total inflow	11,000
Outflow	
Evapotranspiration	9,100
Subsurface outflow:	
To Pine Valley	400
To Southwest	1,700
Total outflow	11,000

1962 to 1991 GW Development Simulation

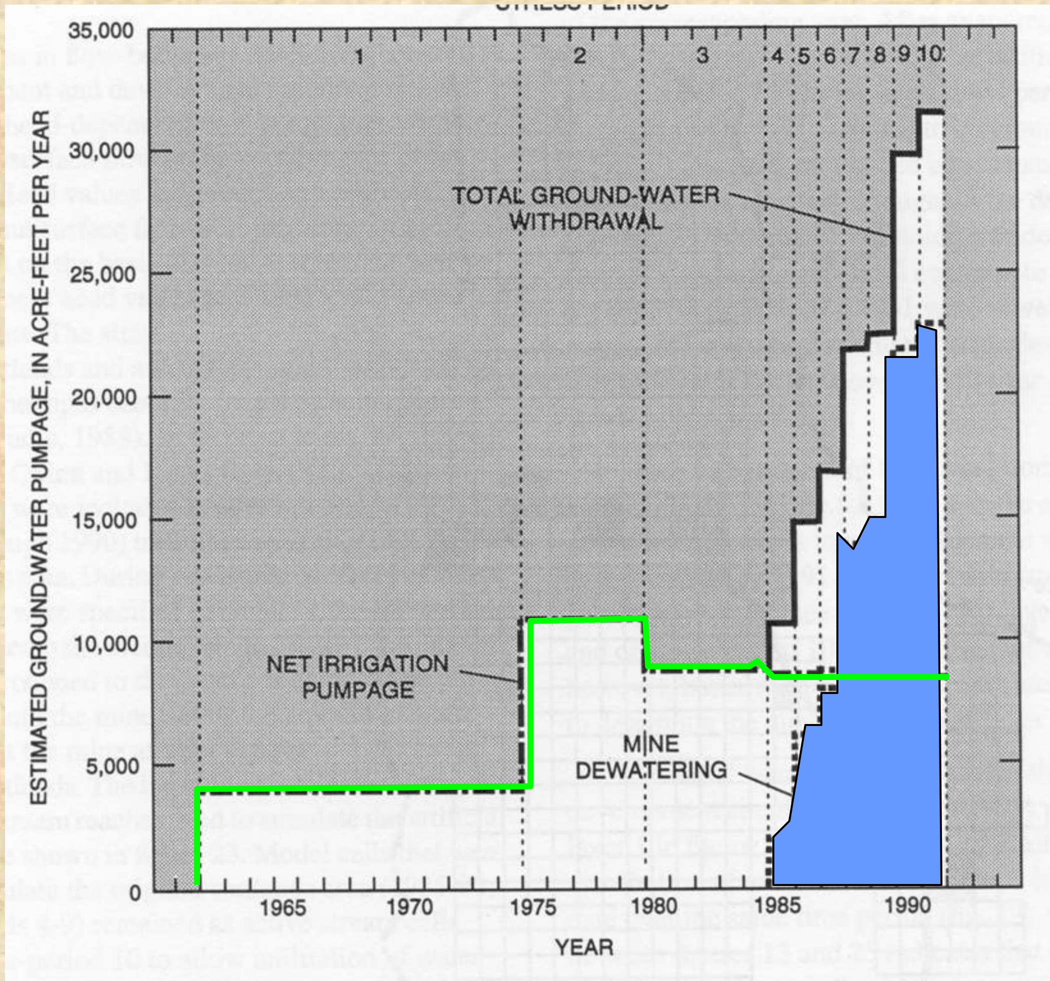
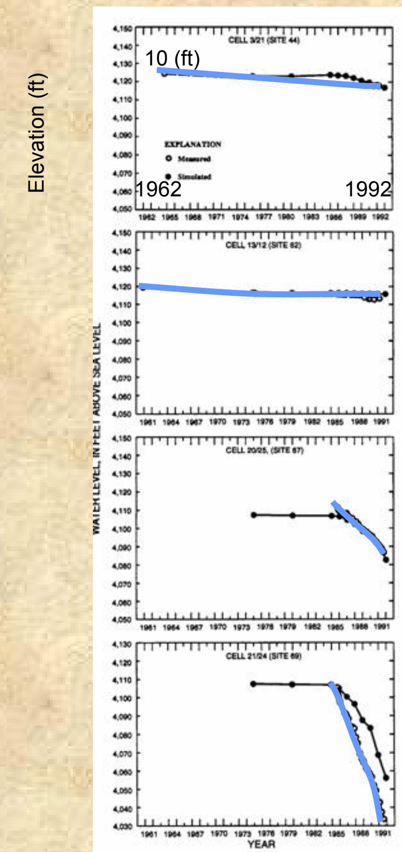


Figure 22. Estimates of net irrigation pumpage, mine-dewatering pumpage, and total ground-water withdrawals, by stress period, specified for development simulation, Desert Valley, Nevada.

History Matching
Transient Calibration

During modeling additional **calibration** **parameter adjustment was completed to yield:**

Water level and flux values in "…matched fairly well



Sensitivity Analyses

In this model:

1. **Evaluated the sensitivity of model results to 5 hydrologic properties using 14 model simulations. Used head changes and calibrated flux rates at boundaries as baseline.**
2. **Halved and doubled parameter values.**

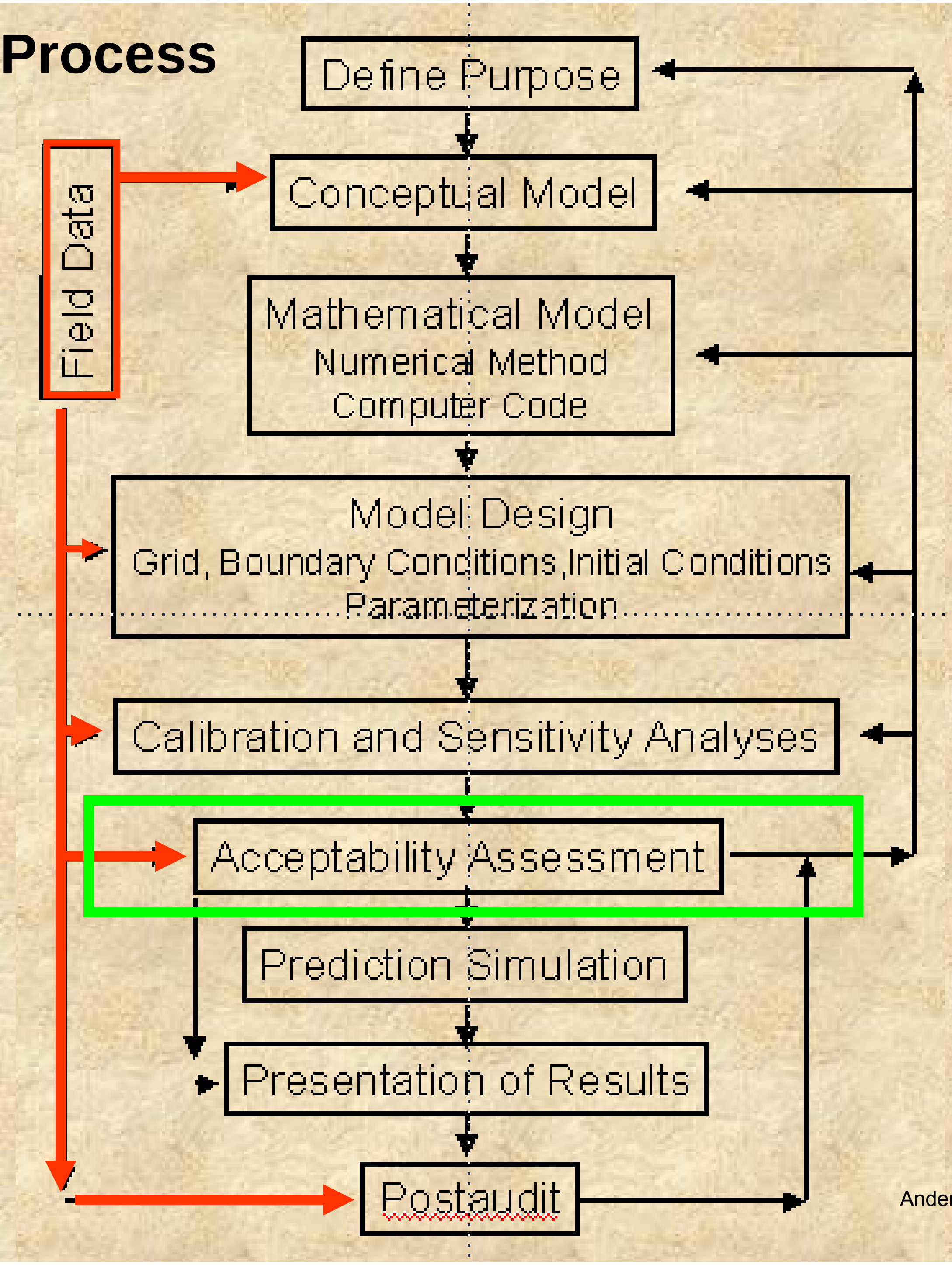
Evaluation:

Model is most sensitive to recharge and plant use (ET) however absolute difference in mean head change is 10 ft.

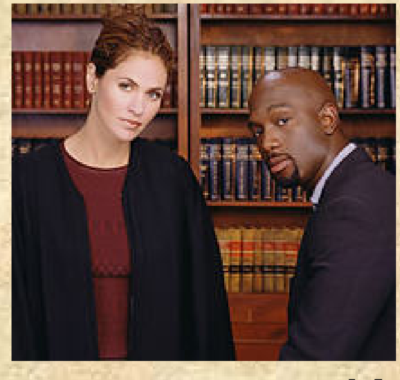
Concluded :

Uncertainty in parameters does not effect general representation of the Gw system sufficiently to negate its use at this point.

Modeling Process



Anderson and Woessner, 2004



Assessing the Calibration and Determining Acceptability

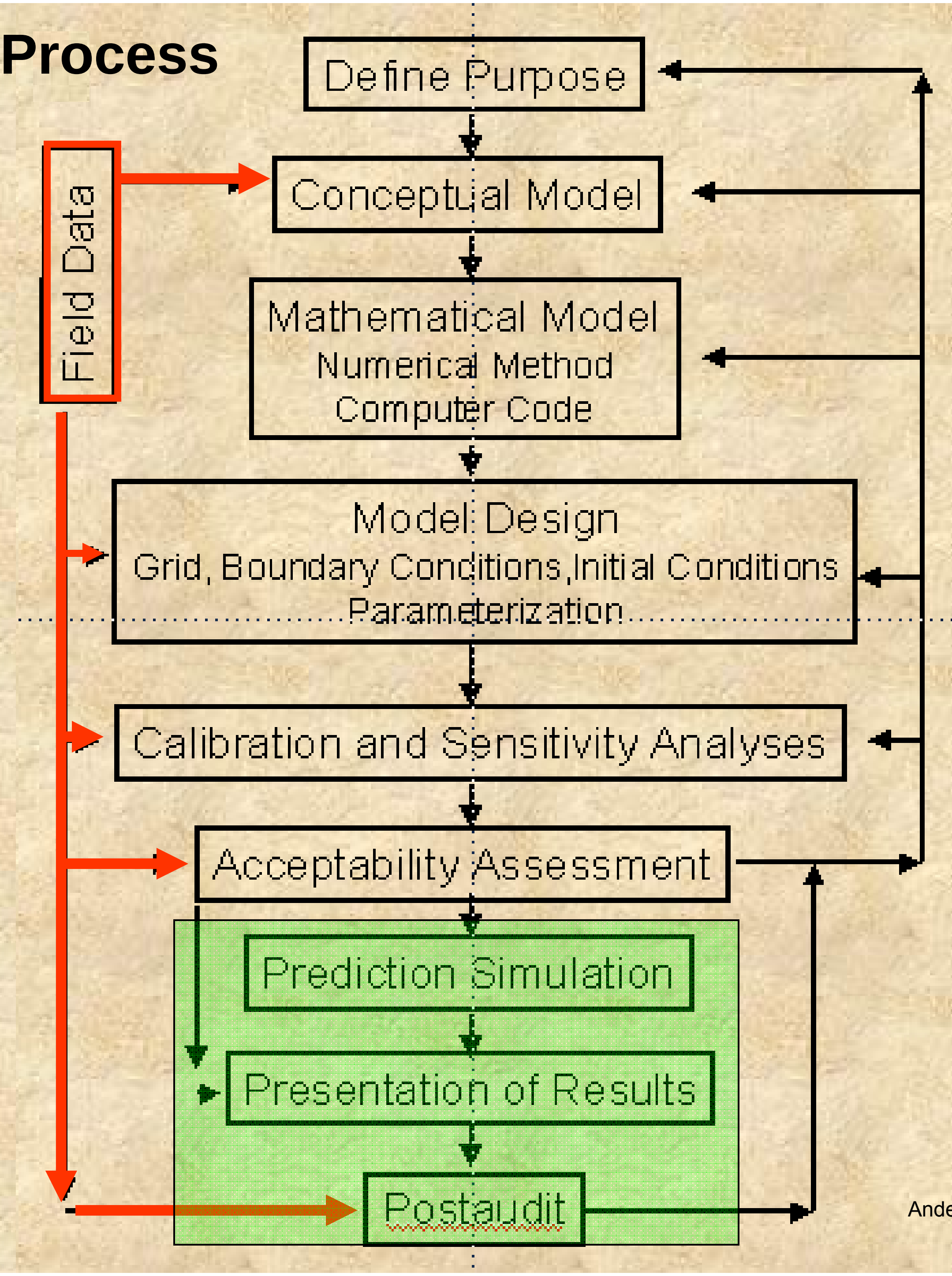
What evidence do you have that a “reasonable representation has been produced?”

Preponderance of evidence /confirming observations documenting performance

Performance measured by closeness of fit with calibration targets and the character and nature of temporal and spatial data

Subjective judgment based on stated model purpose an supporting data.

Modeling Process



Anderson and Woessner, 2004

Prediction or Testing of Three Future De-watering Scenarios (no additional calibrations as no history)

Results of Predictions

1. Water level declines would not be localized around the mine.

2. Declines of 50 ft are simulated at 1 to 2 miles from the mine area.

3. The pumping discharge of water to the wetland retards the expansion of water level declines.

4. Subsurface inflow from the Quinn River Valley occurs.

5. Based on water budgets a new equilibrium may be approached after 100 yr from the time the mine de-watering ceases.

Analyses of 11 Model POSTAUDITs (literature).
How well do predictions match out comes?

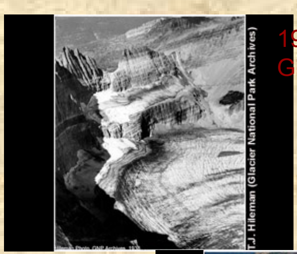
<u>Reported Problems:</u>

1. **Future Stress History and Distribution**

2. **Parameter Values and Distributions**

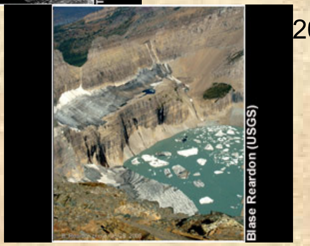
3. **Calibration Conditions Not Appropriate for Predictions,**

4. **Conceptual Model.**



1938 Grinnell Glacier
Glacier NP.

2005 Grinnell Glacier
Glacier NP.



2005

How do You Reduce or Bracket Uncertainty In Model Predictions?

Step 1
Develop a site conceptual model and a calibrated numerical model

↓

Step 2
Develop a number of additional site conceptual models incorporating uncertainties identified in the characterization of site GW/Hydrologic Conditions,
and a number of calibrated Numerical Models

↓

Step 3
Use each calibrated model to predict outcomes.
The range of predictions suggests modeled uncertainty.

Where Does That Leave Us?

Ground Water Models contain uncertainty, however, they are the only tool we have to assess complex settings!

We need to assess uncertainty using multiple conceptual models and present ranges of likely results to decision makers!